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Najafi, Nadia; Schmidt Paulsen, Uwe; Belloni, F.; Mann, Jakob; Bedon, G.

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Dynamic behaviour studies of a vertical axis wind turbine blade using Operational Modal Analysis (OMA) and Experimental Modal Analysis (EMA)

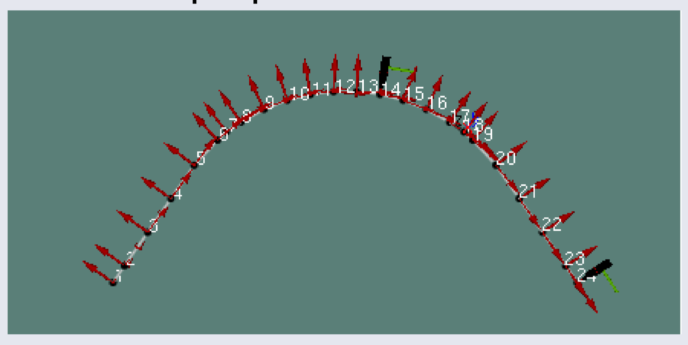
N. Najafi*, U. S. Paulsen*, F. Belloni**, J. Mann*, G. Bedon**
*Technical University of Denmark
**Università di Padova Via Venezia, Padova, Italy

Abstract

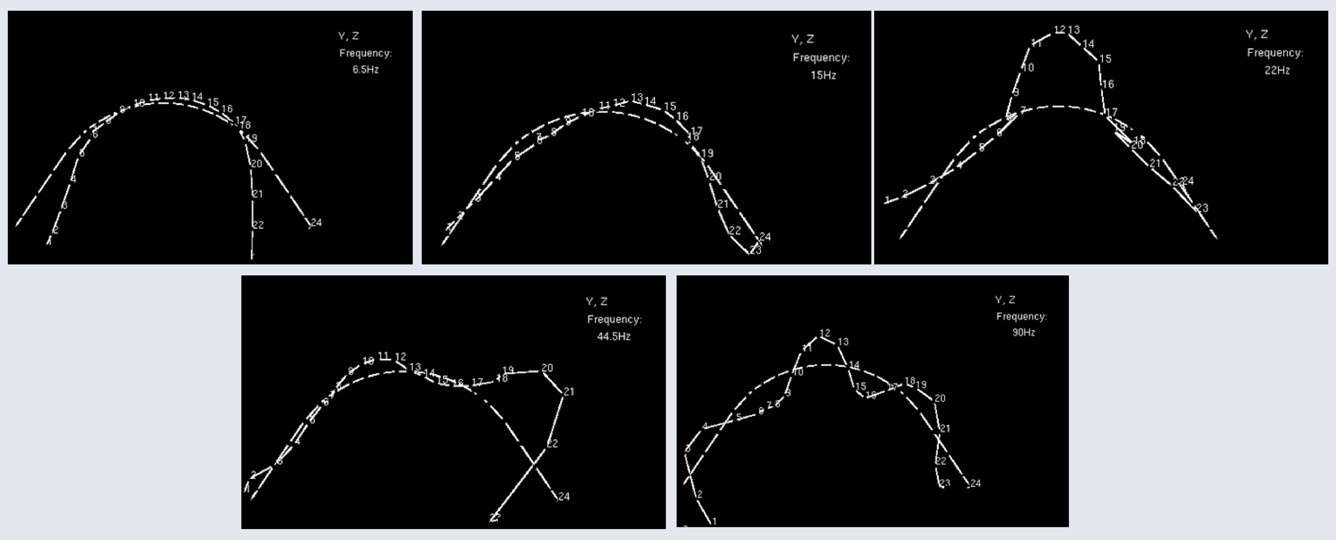
Dynamic behavior of a modified blade fitted onto a small 1 kW vertical-axis wind turbine is studied by two different approaches: Classical modal analysis (EMA) is carried out to validate the results of Operational Modal Analysis (OMA).
In traditional modal analysis (EMA) one axis accelerometers are mounted at different points on the projection of the blade structure centroid line. Measurements are set up in PULSE LabShop software (product of Brüel and Kjær Company). In each measurement set, one reference point is subjected to an impulse force, and acceleration responses are recorded at three different points. This process continues until the data set contains all the points with their degrees of freedom. Finally the frequency response function (FRF) is obtained for all points. and the natural frequencies and the mode shapes are estimated by peak picking method.
Operational Modal Analysis (OMA) is the second approach used in this project in parallel with stereo vision technique. In this method, only the output is required to be measured; actually the input is random and unknown. In this experiment markers are put on the blade centroid projection line (the same place as the accelerometer positions). The 3-D point deflections are monitored in time using stereo vision. Integration is not required for transforming acceleration to deflection in mode shapes identification because we will get deflection directly in this method. Two identical cameras take pictures of the blade and markers while it is excited by random and wind forces. The cameras are programmed in LabView to take pictures at the same time with 180 fps and store them on a high speed hard disk. The output deflection will be investigated in frequency domain by peak picking method, and then AR (Autoregressive) model is applied to describe the structure in time domain. Results of OMA and EMA show good agreement.

Classical Modal Analysis(EMA)

2m rotor diameter is studied by monitoring of the acceleration on 24 points on the blade centroid line by hammering the structure in perpendicular direction



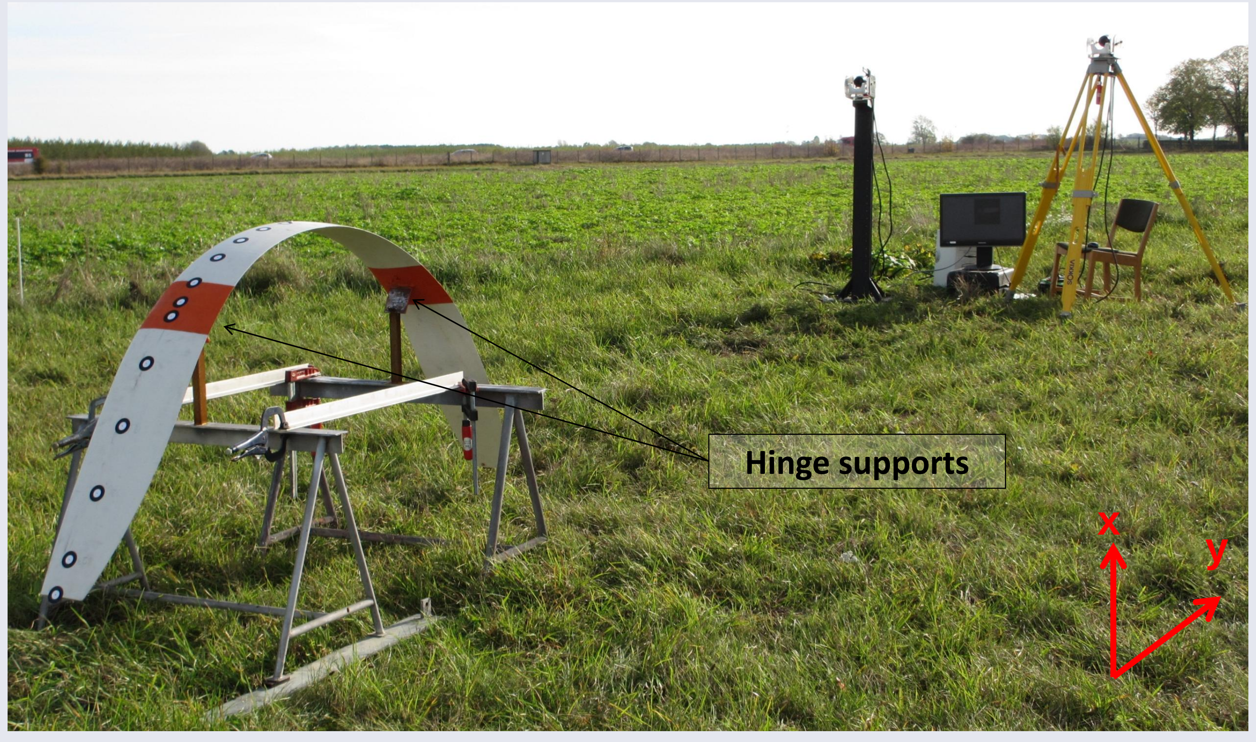
mode shapes are found by Peak Picking method:

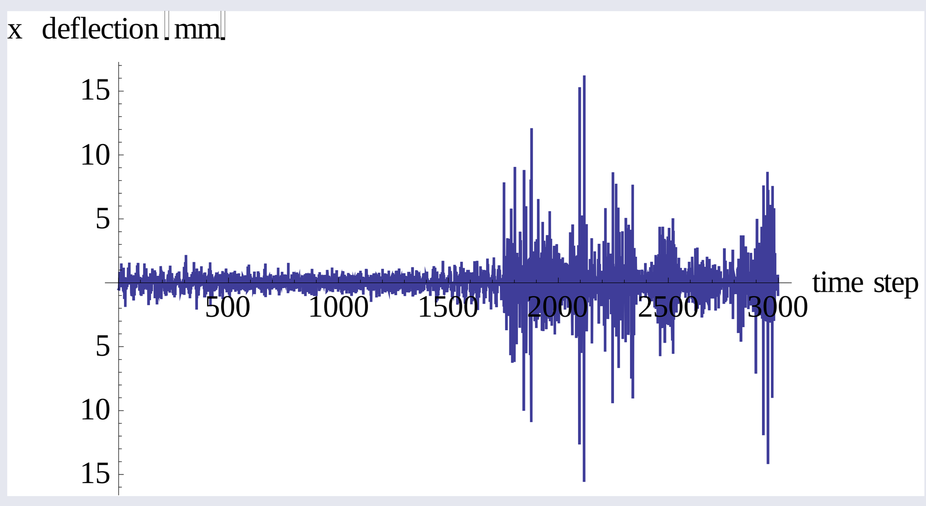


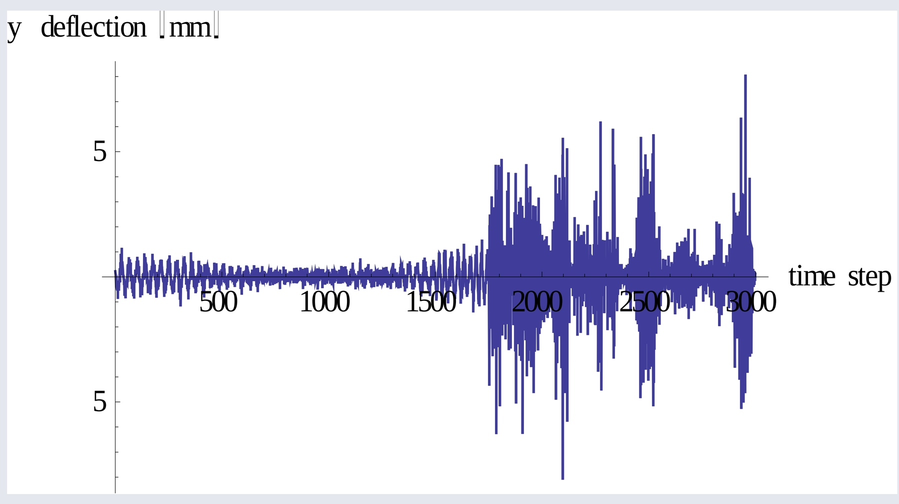
The acceleration responses conducted at the points in the same half area with the hammering point, are affected by the hammering. It is why one have shows bigger deformations.

Operational Modal Analysis (OMA)-Output only

In OMA test, the blade is set outside in the field with the same boundary condition and supports as the EMA test. The 3-D deflections of the markers put on the blade center line are recorded with a stereo vision system (Basler acA2040-180km) in time. the blade while is excited by the wind and other soft finger beats.

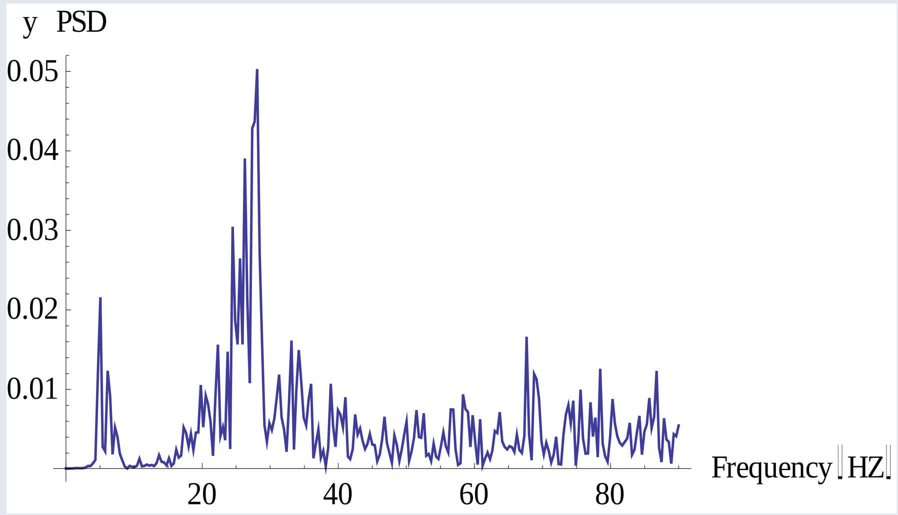


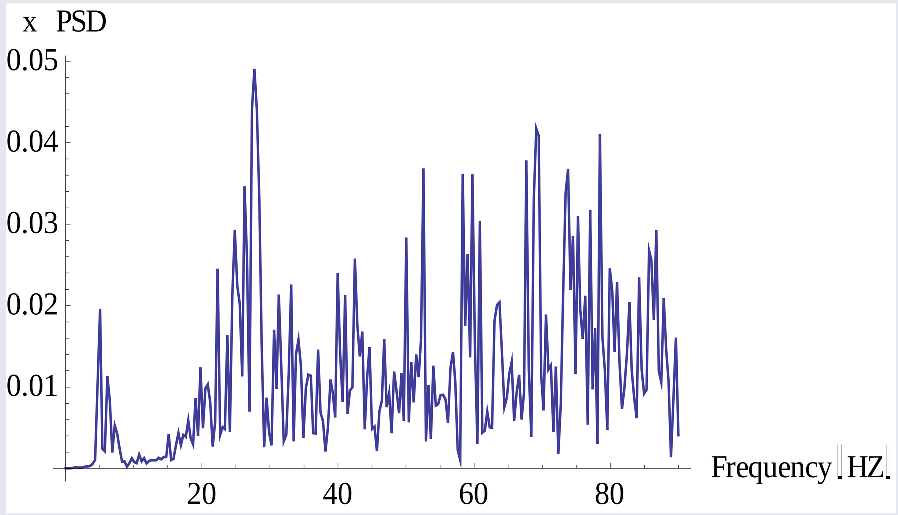




Tip point deflection time series in 16.66 seconds

Power Spectral Analysis





Autoregressive Model

By looking into the state and observation equations of a discrete-time system in state space, ARMA is a suitable method to study the dynamic behavior of a structure in time domain. This method relates the output in each time step to the output in previous time steps and the input [1].

$$y(t) - a_1 y(t-1) - a_2 y(t-2) - \ldots - a_p y(t-p) = w(t) + c_1 w(t-1) + c_2 w(t-2) + \ldots + c_q w(t-q)$$

Random Gaussian white noise → **a high order AR model**

$$y(t) - a_1 y(t-1) - a_2 y(t-2) - \ldots - a_p y(t-p) = e_t$$

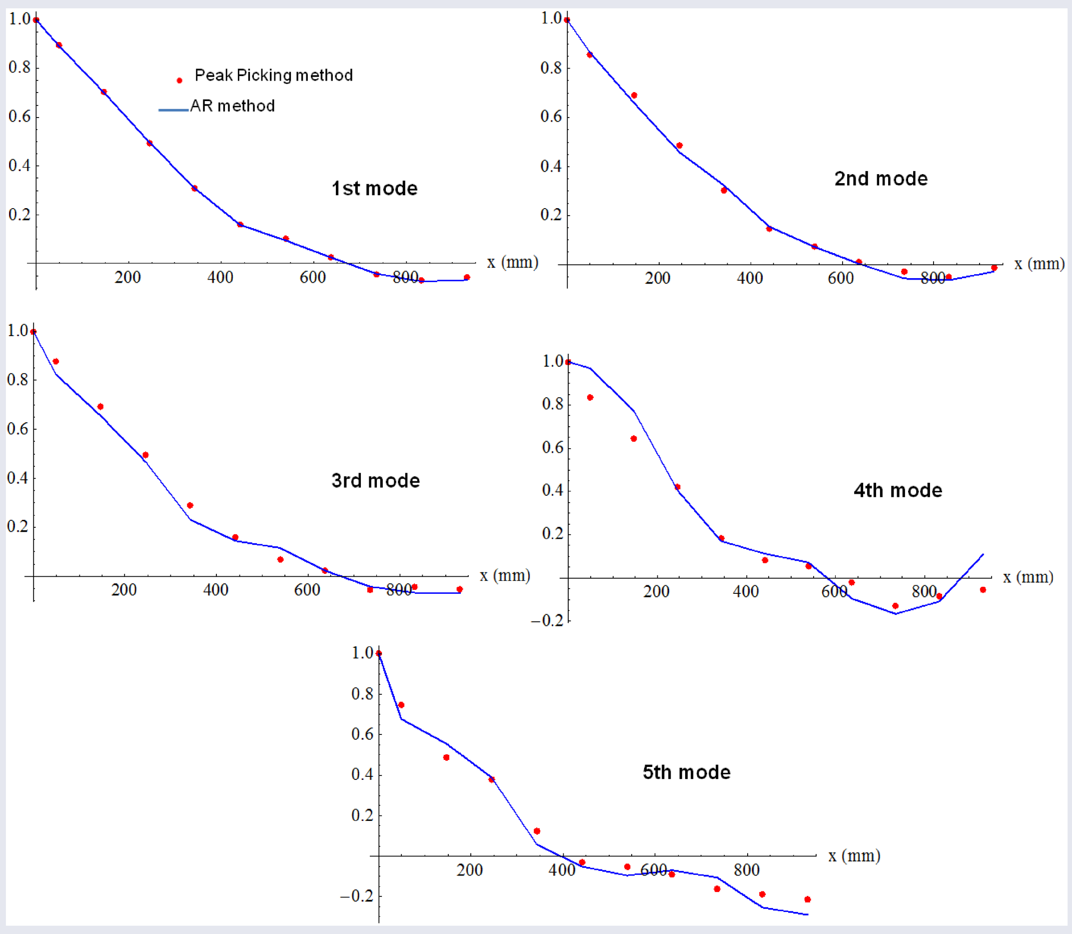
Matrix containing AR coefficients reveals the modal properties of the structure by the solving eigenvalue problem:

$$[\lambda, V] = eig(A) \Rightarrow f_i = \frac{\left|\frac{\ln(\lambda_i)}{T}\right|}{2\pi}$$

$$\xi_i = \frac{\mathrm{Re}\left(\frac{\ln(\lambda_i)}{T}\right)}{\left|\frac{\ln(\lambda_i)}{T}\right|}$$

Results

Mode No.	1	2	3	4	5
Natural Freq. (Hz) EMA	6.5	15	22	44.5	90
Natural Freq. (Hz) OMA - Peak Picking	4.75	19	26.65	41	61
Natural Freq. (Hz) OMA - AR	4.89	22.31	25.5	40.96	60.17
Damping ratio OMA - AR	2.43%	0.91%	1.06%	1.06%	0.64%



Conclusions

Vertical Axis Wind Turbines (VAWT) is under re-newed interest for their potential use and wind direction insensibility of turbulent wind [2] at urban sites, in comparison with the Horizontal Axis Wind Turbines (HAWT). In the current study, the dynamic behavior of a modified VAWT blade intended to be mounted on a modified blade fitted onto a small 1 kW sized wind turbine is investigated structurally by two different approaches: EMA and OMA. In EMA both input and output are used to identify the modal parameters but In OMA the structure is not shaken. On the other hand the input is random and distributed and the output is used for estimating the modal parameters [3].
For this study in the EMA test, there are some known difficulties in the EMA test, such as that the hammer impact affects the recorded response signals. In conclusion OMA has been proposed to avoid these kinds of difficulties. In the current OMA test the blade is tested in the open air, excited by wind forces. The deflections of a few points on the blade centroid line is monitored using stereo vision technique. In this technique two cameras are looking at the moving points in time, so by intersecting two sight lines 3-D coordinates are determined. The point deflection is used as the output for OMA and will be analyzed to estimate modal shapes and natural frequencies. Results of these two different approaches are showing good agreement in terms of mode shapes. However, natural frequency determination show a difference in fifth mode which could be because of finger beats which are not very good uncorrelated and distributed and too short time of conducting a run during the experiment(16.66 seconds).

References

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